

Design Challenge: A Hallway Model of the Atomic Scale

Learning target: I can define precise criteria and constraints for a scale-model exhibit, use calculations about the atomic scale to compare design options, and justify a design decision.

Transfer and design

About 50 min

Pairs

MS-ETS1-1 · assesses

MS-PS1-1 · supports

engineering design

data analysis

writing

Name

Date

Period

Directions

Your school is holding a Family Science Night. The science club has asked your team to design an exhibit in the main hallway that helps visitors feel how small atoms are. Read the brief and the size data. Do the calculations in Part A first; they will show you why this problem is harder than it looks. Then define your criteria and constraints precisely in Part B, compare the three candidate designs in Part C, and make and justify a decision in Part D. Work in pairs; each person completes their own sheet.

You will need: This worksheet, Pencil, Calculator, Ruler, Scrap paper for the decision matrix

The brief from the science club — 'We want visitors, including younger brothers and sisters, to walk away able to say how an atom compares in size with things they know. The exhibit must live in the main hallway, which is 40 meters long and 3 meters wide, and must be set up and taken down the same evening. The club can give you \$25 for materials and two class periods of building time. Nothing may be taped higher than 2 meters, and nothing may block the hallway for wheelchairs or strollers.'

Real sizes (rounded) of the objects to model

Object	Typical width	Width in picometers (pm)
One atom (carbon)	about 150 pm	150
One bacterium	about 1.5 micrometers	1,500,000
One human hair	about 75 micrometers	75,000,000
One grain of sand	about 0.5 millimeters	500,000,000
One basketball	about 24 centimeters	240,000,000,000

Part A: Do the math before you design

1. Complete the table. First divide each object's width by the atom's width (150 pm) to find how many atoms would fit across it. Then convert: if one atom is drawn as a 1 mm dot, the model of each object is that many millimeters wide. Write the model sizes in meters or kilometers where that is easier to read. Show one calculation below the table.

How many atoms wide? (object width ÷ 150 pm)	Model size if one atom = 1 mm dot
Bacterium	
Human hair	
Grain of sand	
Basketball	

2. Using your table, which of the four objects could be shown at the 1 mm-atom scale inside a 40 m hallway? What does this tell you about using a single scale for the whole exhibit?
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-
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Part B: Define the problem precisely

A vague requirement cannot be tested. 'Visitors should understand scale' is vague. 'A visitor can state, within one minute, that a hair is about half a million atoms wide' can be tested. Write your criteria and constraints so that someone could check each one with a yes or no.

3. Write three **criteria** for a successful exhibit. Each must include a number or a clear test (for example, how many objects are compared, how accurately, how fast a visitor can answer a question about it).
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4. Write four **constraints** from the brief, each with its number or limit. Then add one constraint of your own that protects people (visitors or builders) and say why it matters.

5. Pick one of your criteria and one of your constraints and explain how each one rules out at least one possible design.

Part C: Compare three candidate designs

Candidate designs

1 Design 1: One Ruler

A single scale for everything: one atom = a 1 mm dot on a card at the hallway entrance. Tape measures and arrows run down the hallway to the bacterium model (a 10 m chalk circle on butcher paper). Signs at the far end say how far away the hair, sand grain and basketball models would be at this scale ('the hair would be at the park, 500 m away'). Cost: about \$10. Build time: one period.

2 Design 2: Zoom Ladder

Three posters along the wall, each with its own scale. Poster A: one atom = 1 mm, bacterium = 10 m strip along the wall. Poster B: one bacterium = 1 mm, hair = 50 mm, sand grain = 33 cm circle. Poster C: one hair = 1 mm, basketball = 3.2 m strip. Each poster's legend says 'this poster is zoomed out 10,000 times from the last one' (or the true factor). Cost: about \$20. Build time: two periods.

3 Design 3: Count Jar

A jar holding about 10,000 1 mm beads sits on a table with a card: 'If each bead were an atom, this jar holds the atoms in a line across one bacterium. You would need 50 of these jars for a hair and about 330 for a sand grain.' No lengths are modeled; only numbers are shown. Cost: about \$15. Build time: half a period.

6. Score each design against each of your criteria: 2 = fully meets, 1 = partly, 0 = fails. In the constraints row, write yes or name the constraint the design breaks. Add a total.

Design 1: One Ruler	Design 2: Zoom Ladder	Design 3: Count Jar
Criterion 1 (yours)		
Criterion 2 (yours)		
Criterion 3 (yours)		
Meets all constraints? (yes/no, which one fails)		
Total score		

7. Check Design 2's numbers: at the Poster B scale (one bacterium = 1 mm), is a 50 mm hair and a 33 cm sand grain correct? Use the data table and show your work.

Part D: Decide and justify

8. Which design do you recommend, or what change to one of them? Justify your decision using your scores, at least one calculation from Part A, and at least one impact on people. Explain the strongest argument **against** your choice and why you still chose it.

9. Sketch your recommended exhibit as a top view of the hallway (40 m by 3 m). Label the scale used at each place, the clear path for wheelchairs and strollers, and where a visitor would stand to read each sign.



Criteria versus constraints, one more time

A criterion answers 'What must it DO to be a success?' A constraint answers 'What limits are we stuck with?' If a sentence starts with 'must show', 'must let visitors', or 'must be accurate to', it is probably a criterion. If it starts with 'no more than', 'only', 'cannot', or 'must fit', it is probably a constraint. The brief contains at least four constraints hiding in its sentences: find the length, the money, the time and the height.

The Grand Canyon check

The textbook says that if every atom in a grain of sand were as big as a ping-pong ball, they would fill the Grand Canyon hundreds of thousands of times. Test that claim. A ping-pong ball is 40 mm across (volume about 34 cm^3); a sand grain contains roughly 5×10^{19} atoms; the Grand Canyon's volume is roughly $4 \times 10^{12} \text{ m}^3$. Compute how many times the balls would fill the canyon, state whether the textbook's claim holds, and write two sentences about why engineers and writers must check scale comparisons with arithmetic rather than instinct.